REPORT NO. GDC-SP-83-052
CONTRACT NO. NAS 8-35039

DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATION

ORBIT TRANSFER VEHICLE SERVICING

VOLUME 1 — EXECUTIVE SUMMARY

June 1983

GENERAL DYNAMICS
Convair Division

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FOREWORD

This study report was prepared by General Dynamics Convair Division (GDC) for the National Aeronautics and Space Administration Marshall Space Flight Center (NASA/MSFC) in accordance with Contract NAS8-35039, Data Requirement Number DR-4. The results were developed from October 1982 to June 1983. Final documentation is provided in two volumes:

Volume 1	Executive Summary
Volume 2	Study Results

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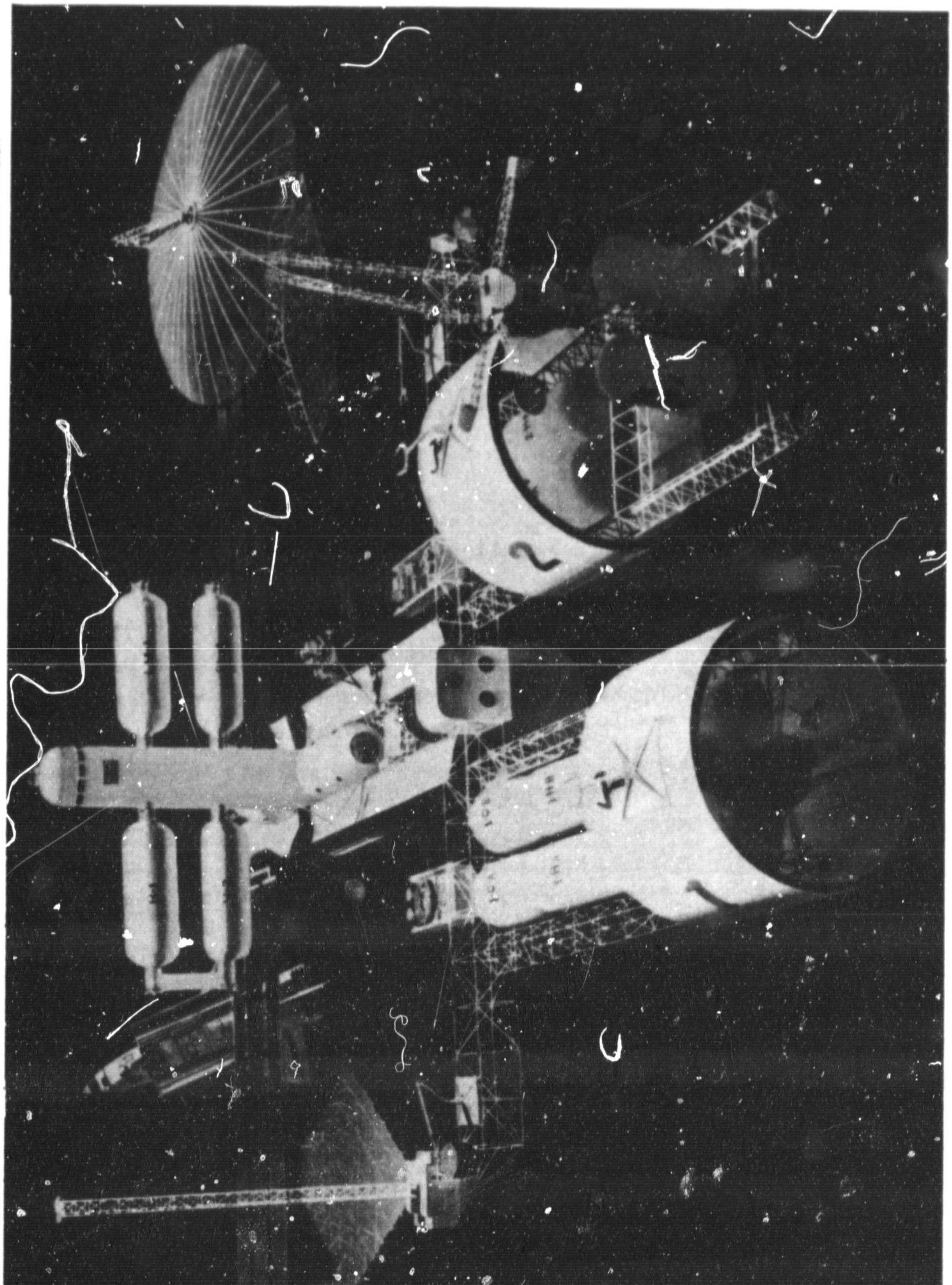
ACRONYMS

ACS	Attitude Control System
AEU	Aft Electrical Unit
ATP	Authority to Proceed
CCW	Counter Clockwise
CDR	Critical Design Review
CG	Center of Gravity
C&W	Caution and Warning
DDT&E	Design, Development, Test and Evaluation
EMU	Extra-vehicular Maneuvering Unit
ET	External Tank
EVA	Extra-vehicular Activity
GDC	General Dynamics Convair Division
GEO	Geostationary Earth Orbit
GH_2	Gaseous Hydrogen
IMS	Integration Management System
I/O	Input/Output
IOC	Initial Operating Capability
I_{sp}	Specific Impulse
IVA	Intra-vehicular Activity
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LH_2	Liquid Hydrogen
LRU	Line Replaceable Unit
LO_2	Liquid Oxygen
MLI	Multi-Layer Insulation
MM	Manned Mission Module
MSFC	Marshall Space Flight Center, NASA
OTV	Orbital Transfer Vehicle
PDR	Preliminary Design Review
P/L	Payload
RCA	Remote Controlled Arm
RF	Radio Frequency
RMS	Remote Manipulator System
R/R	Remove/Replace
RU	Replacement Unit
S/C	Spacecraft
SS	Space Station
STS	Space Transportation System
TBD	To be Determined
TDM	Technology Development Mission
TMS	Teleoperator Maneuvering System
TV	Television



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1.0 OTV SERVICING STUDY SCOPE

Currently, all upper stages and/or orbital transfer stages are of the expendable type. With the operational capability of the Space Shuttle, this mode of operation will change and these stages will become reusable. With the coming of the manned space station, the OTV will evolve further to a more capable, higher technology system. Studies have shown that a change from ground-based to space-based OTVs offers improved operational economy, better vehicle performance, freedom from the constraints of Orbiter payload bay dimensions, and freedom from the constraints of ground operation schedules.

A space-based OTV requires that servicing be performed in orbit to accomplish turnaround of the vehicle for subsequent flights. This servicing would most likely be performed at a Space Station. This study effort addressed both the OTV and the Space Station by identifying and defining the servicing capability requirements. The term "servicing" is used in a broad sense, encompassing not only direct servicing operations such as refueling, repair, and checkout, but also related support activities such as payload/OTV integration, docking/berthing/handling, logistics/storage, and prelaunch/postlaunch processing.

The study (1) defined the testbed role of an early (1990) manned Space Station in the context of a space-based OTV evolutionary development and flight demonstration technology plan which would result in an OTV servicing operational capability by the mid 1990's, and (2) conceptually defined a set of OTV servicing technology development missions (TDM) to be performed on an early Space Station.

Our study was based on systematic examination of end-to-end operations postulated for an OTV engaged in routine missions to and from the Space Station. In a sense, we generated a top level definition of a capability similar to that of launch centers on the ground. We kept this parallel in mind so that our study considered all aspects of OTV servicing.

We began by identifying mission requirements for space-based OTVs, and the operational space-based OTV capabilities needed by the mid 1990s. We identified space-based OTV servicing capabilities that must be demonstrated by ground tests, Shuttle sortie tests, and early Space Station tests. This analysis enabled us to illustrate the testbed role of an early Space Station by developing the technology objectives and requirements for missions that are forerunners of actual operations in the space-based mode. Next, we generated conceptual designs of the tests proposed to be performed on the initial Space Station in the areas of propellant transfer/storage and reliquefaction, docking and berthing, maintenance, and OTV/payload integration. We performed trade studies to optimize the designs. An end-to-end mission operations analysis was performed in each of the above areas which defined the timelines, manpower, and support equipment requirements. In addition, accommodation requirements on the initial Space Station were identified. Finally, we developed the programmatics and preliminary cost estimates for accommodating the selected TDMs.

Under subcontract, Hamilton Standard assisted us in the mission definition and operations analysis tasks. Using their extensive experience in areas dealing with current EVA integration, operations, and applications, they made direct contributions to requirements, concepts, trade studies, and operations analyses.

This study was performed simultaneously with the "Space Station Needs, Attribues and Architectural Options" study for NASA Headquarters. That study also performed investigations related to a Space Station OTV base. We setup close cooperation between the study teams to assure maximum information flow and generated detailed task planning to assure no duplication of effort. Each study effort benefited significantly from the combined activities.

1.1 OTV MISSION REQUIREMENTS

We investigated potential OTV mission scenarios based on the current data base. In our analysis we determined that the Space Transportation System Nominal Mission Model (FY-1983-2000) Revision 6, October 1982 prepared by Donald Saxton, Program Development, MSFC was the most comprehensive for the 1990-2000 time period and included data for all the potential users. Thus we used the data in this mission model to generate the OTV mission requirements. Figure 1-1 shows the driving design requirements for the space-based OTV to meet the mission model. It shows the maximum delivery payload weights envisioned for a single flight. The unmanned and manned servicing mission requirements are also design drivers, especially the return payload requirements.

	Weight (Klb)	Mission
Operational GEO platform	14.0	Deliver
Large platform	Multiple OTV flights	Deliver
Other satellites	Multiple satellites to 14.0	Deliver
GEO station element	16.0	Deliver
Unmanned servicing	6.0 up 2.0 down	Round trip to GEO
Manned sorties	13.0 up 13.0 down	Round trip to GEO
Solar system exploration	Up to 12.0	Escape

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Figure 1-1 Mission Model Payload Requirements

1.2 REPRESENTATIVE SPACE-BASED OTV CONCEPT

In order to understand the space station servicing functions for a space-based OTV and design TDMs to develop the technologies for these functions, we felt that we needed a strawman space-based OTV. An OTV optimized for the space environment and on-orbit maintenance will differ greatly from its ground-based counterpart and will offer significant advantages. Potential OTV concepts must address the key issues shown in Figure 1-2. Our baseline vehicle, illustrated on the upper left, attempts to do this within the limits of the study scope and served as a basis for generating the servicing requirements. A NASA Headquarters/MSFC Concept with many good features is shown on the lower right.

The baseline Orbital Transfer Vehicle Concept (see Figure 1-3) is for an advanced OTV designed specifically for the space environment and with modular philosophy to simplify logistics, maintenance and reconfiguration for different missions. Vehicle elements peculiarly adaptable to a space-based vehicle are summarized below:

- Lightweight Spherical Propellant Tanks
- Modular Tankage Arrangement for Mission Flexibility
- Fixed Aerobrake
- Lightweight Open Truss Structure

Advantages
- Free from Shuttle constraints (size, loads)
- Reusable (lower cost)
- Modularity (mix & match capability)

Key issues
- Long-term space exposure
- Orbital integration, servicing
- Efficiency (low weight, high Isp)
- Low-cost operations (propellant delivery to LEO)
- Deployment & retrieval
- Future payloads & mission characteristics

Technology needs
- Lightweight (thin gage) tanks
- Lightweight (composite) structure
- Lightweight/high temperature aerobrake materials
- Long life/space maintainability engine (low weight, high Isp
- Cryogenic propellant management — thermal control (MLI insulation, mixing, venting), propellant acquisition gaging
- Meteoroid & space debris protection
- Redundant, fault-tolerant, hardened avionics
- Auto rendezvous/docking

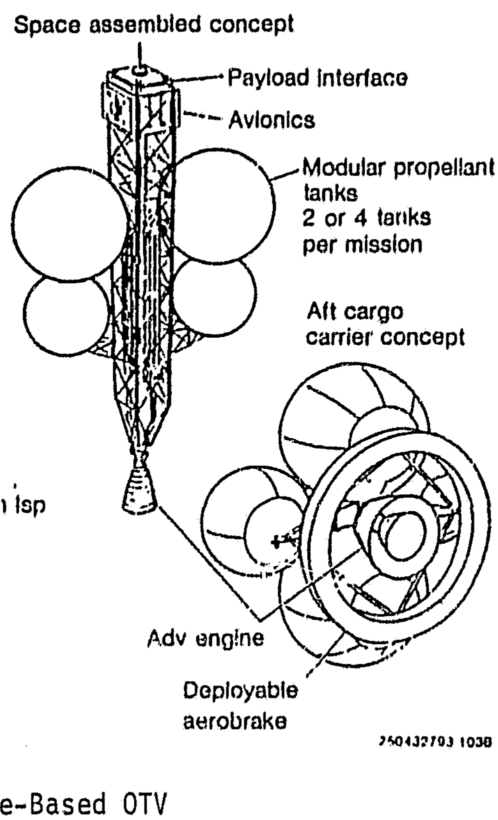

Figure 1-2 Space-Based OTV

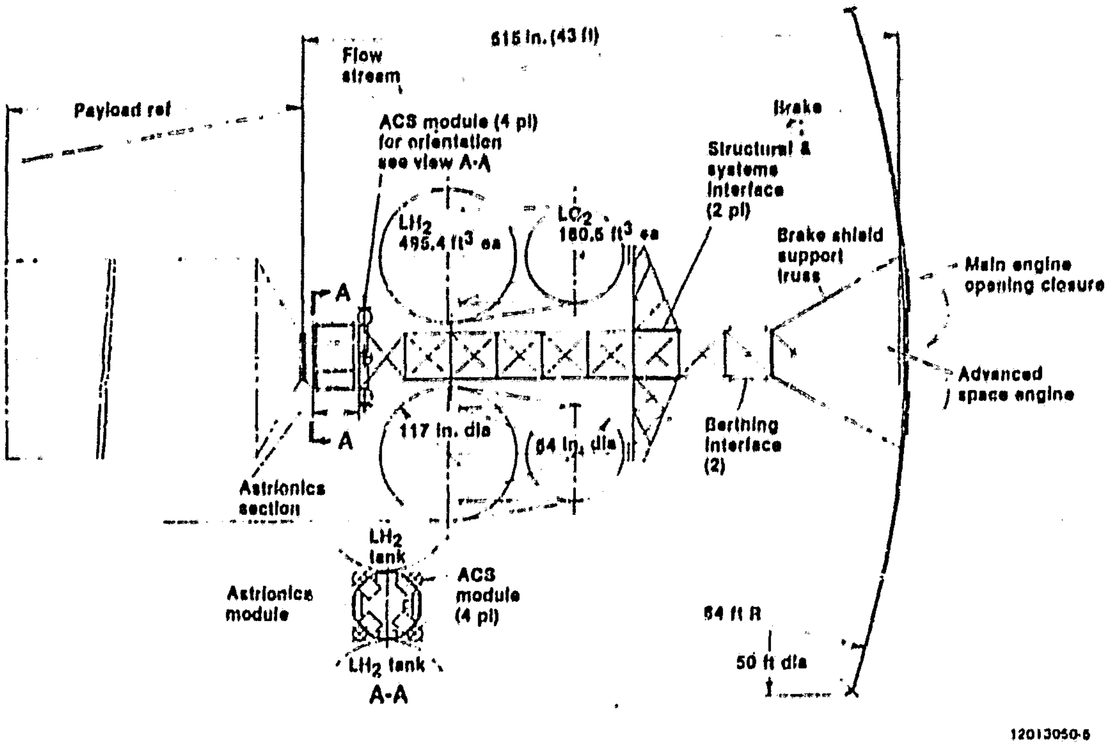

Figure 1-3 Representative Space-Based OTV Concept

- Universal Payload Interface Module
- Quick Changeout Astrionics, ACS, Propellant Feed and Main Engine Modules
- Fixed High Area Ratio Engine Nozzles

The vehicle is sized to meet the mission requirements of the MSFC Nominal Mission Model, Rev. 6.

1.3 SELECTED TECHNOLOGY DEVELOPMENT MISSIONS (TDM)

Having identified the OTV mission requirements, we then performed an OTV mission functional/operational analysis to identify the required servicing functions to be performed on the space station. The functions identified were 1) propellant transfer, storage reliquefaction, 2) docking and berthing, 3) maintenance, and 4) OTV/payload integration. These functions were analyzed further in order to determine what functions should be tested in an evolutionary sequence, with emphasis on the tests that must be performed on the initial Space Station.

We constructed an OTV development test matrix to identify the testing level (ground, Shuttle sortie, Space Station) of the development tests. The major driver in specifying a space test was the impact of a zero-g environment. Discriminators between Shuttle sortie and Space Station testing were zero-g testing time, test setup weight and volume constraints of the Orbiter (scaling effect), and the economics of using the manned Space Station. We prioritized the tests to determine the order in which they should be performed to develop the OTV servicing capability. Using the descriptions of the Space Station tests, the TDM objectives and requirements were generated to drive the TDM conceptual designs.

Because it is useful for a study as complex as this to have an overall visualization of a space-based OTV system in operation, we used an artist's concept of such a system as shown in the frontispiece to help guide the design of the selected TDMs. The origin of this was not in the current funded Space Station studies, but resulted from some prior in-house OTV studies. Shown are two OTV servicing stations. The one at the left shows an OTV in a maintenance position housed within a movable servicing hangar. The second view shows an OTV rotated to a loading position for propellant loading and for payload installation prior to flight. These views were extremely useful for identification of the numerous operations and maintenance functions that are involved in the total scenario.

Using the mission requirements for the selected functional areas for Technology Development Missions (TDM), the space-based OTV concept defined in the previous section, and the concept of operational OTV servicing shown in the frontispiece, we generated candidate conceptual designs for the TDMs. Alternative designs were generated for each TDM and a combined TDM was also generated. System level trade-off data and inputs from the operations tasks were analyzed during the study in order to arrive at the optimum definition for each TDM. This information is contained in Sections 2.0 thru 6.0.

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2.0 PROPELLANT TRANSFER, STORAGE AND RELIQUEFACTION TDM

The TDM definition includes a summary of the evolutionary technology development plan with the emphasis on the tests to be performed at the initial space station, the conceptual design, and the end-to-end operations requirements.

The capability to transfer, store for a long period of time and reliquefy cryogenic propellants under zero-g conditions in space must be developed. Our experience with handling cryogenics in space has only been under some "g" conditions, and for a relatively short period of time. No reliquefaction of cryogenics has been attempted. Shuttle sortie tests are proposed to prove the feasibility of performing the transfer and long term storage functions under zero-g conditions, but the time constraints of the shuttle mission prevent the development of the required data base, under varying conditions, to provide the confidence to proceed with an operational program. The proposed TDM provides the capability to generate a sufficient data base to provide the confidence level needed. The TDM allows for sufficient time under zero-g conditions and a desirable scaling factor to satisfactorily predict the full scale behavior of the cryogenic propellants.

2.1 REQUIREMENTS

The operational/functional analysis we performed for the OTV mission identified the functional areas to be developed, as called out on Figures 2-1 and 2-2. The figure also indicates the development tests to be performed in an

Function	Development Tests: Ground	Development Tests: Shuttle Sortie	Development Tests: Station	Rationale for Space Station Test
Make docking fluid interface connection	X	X	X	Dependent on configuration, significantly different from the ground or shuttle tests. Space shuttle envelope is limited
Chilldown fluid transfer line	X	X	X	Space station envelope different from the shuttle configuration. Difficult to parameterize
				Operational transfer line different in length & diameter. The quality of the fluid changes by changing flow rates, length & diameter of line & heat transfer to the fluid. Different pressure surges
Chilldown receiving tank	X	X	X	Chilldown consists of repeated charging, hold & vent cycles until the specified temperature & pressure is reached
				Test tank with the scaling factor of 0.37 is large enough to accurately predict the performance of the operational tank
Transfer propellant to receiving tank	X	X	X	Physical demonstration using operational configuration to maintain thermal equilibrium & low tank pressure
				Determine operational pressure histories, flow rates, number spray nozzles & test instrumentation
Disconnect docking fluid interface	X	X	X	Same as function 1

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Figure 2-1 Propellant Transfer Development Tests Matrix

Function	Development Tests			Rationale for Space Station Test
	Ground	Shuttle Sortie	Station	
Condition/Quantity monitoring	X	X	X	Thermo/Hydrodynamic operational exp analysis
Insulation	X		X	Demonstration of thermal performance of an operational MLI & attachments. Space station mounting & tank penetrations are different from previous tests
Shadow shielding	X		X	Refine ground design to achieve lowest propellant loss. Shield spacing is large. Each shield radiates to space instead of only to its neighbor
Meteoroid protection	X		X	Thin radiation shields if unprotected are vulnerable to meteoroids. Should shields be penetrated the thermal performance of the MLI is reduced
Propellant acquisition	X	X	X	Full screen acquisition device, completely passive; conceptual design available. Flight test in the late 8Cs
Stratification/Pressurization/ Mixing	X	X	X	Stratification causes liquid/vapor interface problems, thus increasing heat transfer between L&V, may result in ullage pressure collapse
			X	Mixing required to destroy fluid temperature stratification, minimizes pressure rise, lowers need for venting
Venting	X		X	Thermodynamic vent system. Liquid venting would impose intolerable weight penalties
Reliquefaction	X		X	The Stirling or Brayton cycle refrigerator will be used based on lowest equipment weight & volume per kW refrigeration requirement, projected maintenance-free operation & development history & availability
Start/Restart engine Dotank	X		X	The acquisition system is the key element for providing gas-free liquid in the zero-g operational environment

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Figure 2-2 Propellant Storage Development Tests Matrix

evolutionary manner on the ground, on Shuttle sortie missions and on the initial Space Station. The rationale for the Space Station tests is presented. TDM objectives and requirements were developed for the recommended Space Station tests. Figure 2-3 is a sample of these objectives and requirements which drove the conceptual design.

A representative schematic of a LH_2 propellant transfer, storage and reliquefaction system is presented in Figure 2-4 to help understand the functions being discussed. The system consists of supply and receiver components. Propellant transfer is done by using a pump with a full screen propellant acquisition device. The supply tank contains subcritical fluid and requires the acquisition device for providing liquid to the transfer line. A thermodynamic vent system provides liquid free venting during storage. Multilayer insulation is required to maintain low incident heat flux to the stored cryogen. The transfer lines are designed for low heat leak and efficient chilldown. The tanks have inlet diffusers and nozzles to minimize vented fluid during chilldown and fill. A reliquefaction unit is used to reliquefy fluid vented from either the receiver or supply tank during storage, transfer and chilldown. The resultant liquid is returned to the supply tank.

Function	Objectives	Requirements
Venting	**Determine:** • Thermodynamic vent system effectiveness in space **Monitor:** • Bulk heat exchanger temperature • Vapor return to reliquefaction system • Tank pressure	• Thermodynamic vent system with heat exchanger & mixer • Liquid-free venting • Tank pressure: 18-25 psi
Reliquefaction	**Verify:** • Performance of the total system using a Stirling or a Brayton cycle refrigeration system **Determine:** • Propellant quantity reliquefied	• Use Stirling or Brayton cycle refrigeration system • Low equipment weight & volume • Available & maintenance-free equipment • Space radiator & solar array • Expel gas-free liquid
Start/Restart Engine/detank	**Demonstrate:** • Propellant acquisition system performance in zero-g • Capability of system integrated with operational tank pressure control system • Propellant unloading in zero-g	• Expel gas-free liquid

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Figure 2-3 TDM Objectives & Requirements – Propellant Storage

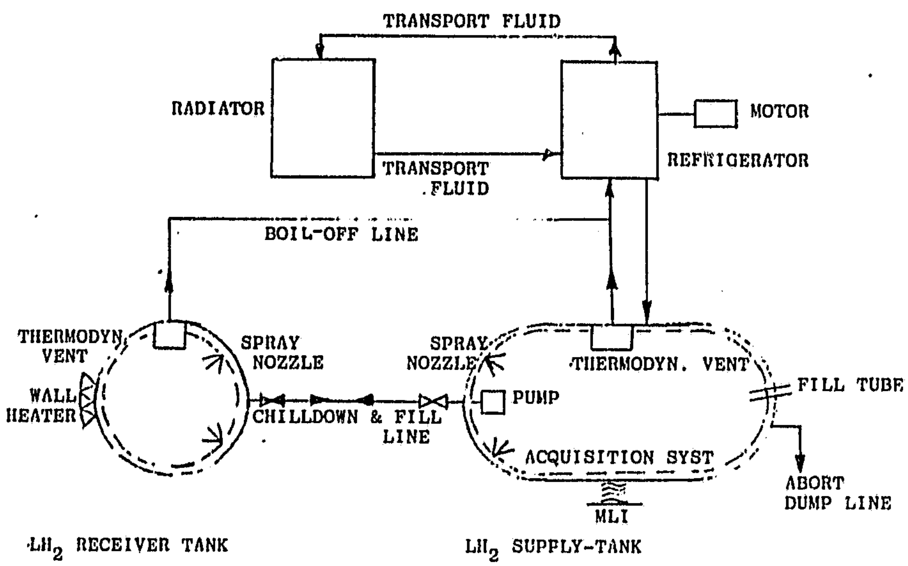

Figure 2-4 Typical Propellant Transfer, Storage and Reliquefaction System

A preliminary hazard analysis was undertaken to examine the safety aspects of storing and transferring LH_2 and LO_2 aboard the Space Station for the fueling of a space-based OTV. This was done in order to determine if a separate free flying propellant depot would be required. Potential hazards were identified and recommendations to eliminate these hazards were developed. From the results of the analysis, we feel that the LH_2 can be safely stored at the station if the recommendations are incorporated into the design.

2.2 CONCEPTUAL DESIGN

Figure 2-5 shows the recommended TDM design along with a preliminary weight statement. The equipment follows the system schematic shown in Figure 2-4. The requirements described in Section 2.1 along with the design recommendations from our safety analysis were used as the design drivers of the system. In addition, the size of the receiver tank was obtained from the performance analysis on our representative space-based OTV described in Section 1.2. The size of the LO_2 tank from that analysis turned out to be 84 inches in diameter. This is approximately .37 times the volume of the required LH_2 capacity. We feel that a scaling factor in this range is required to predict the behavior of the cryogenic propellant in the full size vehicle. From our experience with LH_2 testing and the size of the test tank (87 in. dia) being tested at MSFC presently, we determined that the capacity of the LO_2 tank would be ideal for the receiver tank for our proposed TDM. The launch configuration of the TDM is shown in two views on Figure 2-5 along with the equipment attached to the Space Station and the radiator deployed. The Space Station interface is discussed in Section 6.0.

Equipment	Wt (lb)
Receiver tank	96
Receiver tank acquisition system	65
Receiver tank MLI	25
Supply tank	170
Supply tank acquisition system	230
Supply tank MLI	108
Transfer lines	182
Data control & interface electronics	290
Electrical system	190
Shuttle interface lines	162
Supporting truss structure	580
Space station controls & displays	170
RMS	350
Propellant reliquefaction body structure	200
Propellant reliquefaction equip	600
Radiators	460
LH_2	2,032
Total	5,899

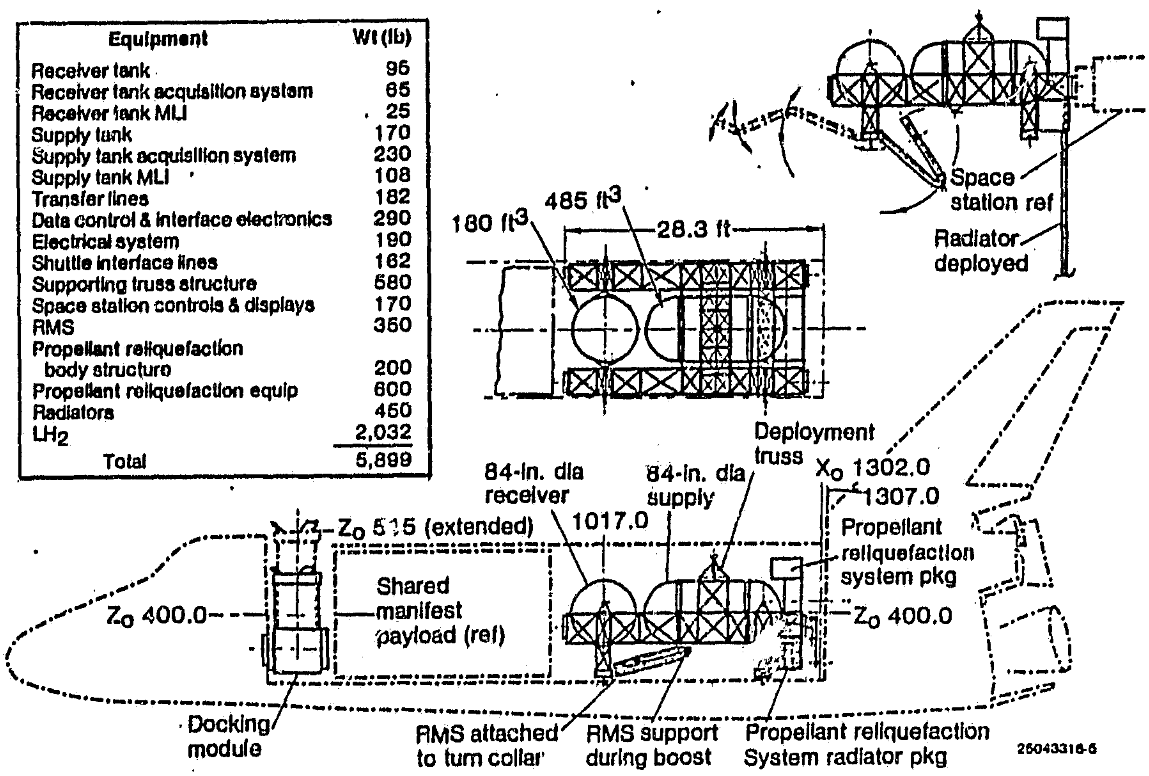

Figure 2-5 Propellant Transfer, Storage & Reliquefaction TDM

2.3 TDM OPERATIONS

Functional/operational flow diagrams along with timelines were generated for this TDM. The operations start with the docking of the orbiter to the Space Station and continue thru the unloading of the TDM equipment, the attachment of the equipment to the Space Station and its checkout, and the performance of the TDM activities. GD analyzed how to perform the functions in space and whether they should be mechanized or performed by the crew doing EVA or IVA and what support equipment was required. We called upon our experience with cryogenic upper stages on the ground as a starting point to analyze and select the way a task should be done in space. The top level timeline for this TDM is presented in Section 7.0. Detailed functional flows and timelines are provided in Volume 2.

3.0 DOCKING AND BERTHING TDM

The capability of a space-based OTV to operate in the vicinity of and to dock and berth to the Space Station must be developed. Simulations can be performed on the ground and some additional development can be carried out on Shuttle sortie missions. Time constraints on sortie missions prevent the development of the required data base, under varying conditions, for various techniques, such as OTV direct docking, using a TMS to direct dock the OTV, or capturing the OTV with an RMS for docking. In addition, the capability for automated docking must be investigated. The proposed TDM provides the capability to generate a sufficient data base to provide the confidence level needed to proceed with an operational program.

3.1 REQUIREMENTS

Figures 3-1 and 3-2 provide a summary of the functional areas to be developed and the development tests to be performed in an evolutionary manner. TDM objectives and requirements for the recommended Space Station tests were generated and the requirements are summarized in Figure 3-3.

In order to meet the test objectives and mission requirements, a free flying OTV test bed would have to be constructed. This would be very expensive so we looked around for an alternative approach to carrying out the Space Station development tests.

Function	Development Tests			Rationale for Space Station Level Test
	Ground	Shuttle Sortie	Space Station	
Docks OTV with space station				
• Stability & control system	X	X	X	• Ground checkout tests of all the system components & system. In addition, a ground simulator is required
• Monitor & control system	X	X	X	• Shuttle sortie tests using a TMS to simulate OTV
• Communication	X	X	X	• Verify docking operation on & around a space station configuration both for the hardware & the procedures. Check out automated & manual backup
• Docking system	X	X	X	

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Figure 3-1 OTV Docking Development Tests Matrix

Function	Development Tests			Rationale for Space Station Level Test
	Ground	Shuttle Sortie	Space Station	
• Berthing system	X		X	• Ground checkout tests of all the system components & system • Shuttle sortie tests on zero-leak fluid disconnect • Verify berthing hardware & procedures integrity on space station configuration
Alignment sensors	X			
Contact sensors	X			
Coupling & access	X	X		
Manipulators	X			
• Monitor & control	X		X	
Indicators	X			
Controls	X			
Instrumentation	X			

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Figure 3-2 OTV Berthing Development Tests Matrix

Function	Requirements
Stability & control system	Test required to determine that stability & control system performs as designed with respect to thrust, response, tracking accuracy, fuel consumption & attitude maintenance. Use simulated OTV software & hardware. Measure response levels
Communications	Use radio link, TV system & distance ranging equipment during docking with station. Measure errors, system noise & directivity
Docking system	Provide simulated OTV attachment hardware to assess performance. Measure actuation times, forces required for actuation/release & cock-angles. Measure sensitivity, thresholds, hysteresis & visibilities
Berthing	Berth OTV simulator to station. Determine that liquid, gas & power ports match & seal
Monitors & controls	During docking of OTV simulator with station, determine that displays, controls & safety devices function

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Figure 3-3 TDM Mission Requirements - Docking and Berthing

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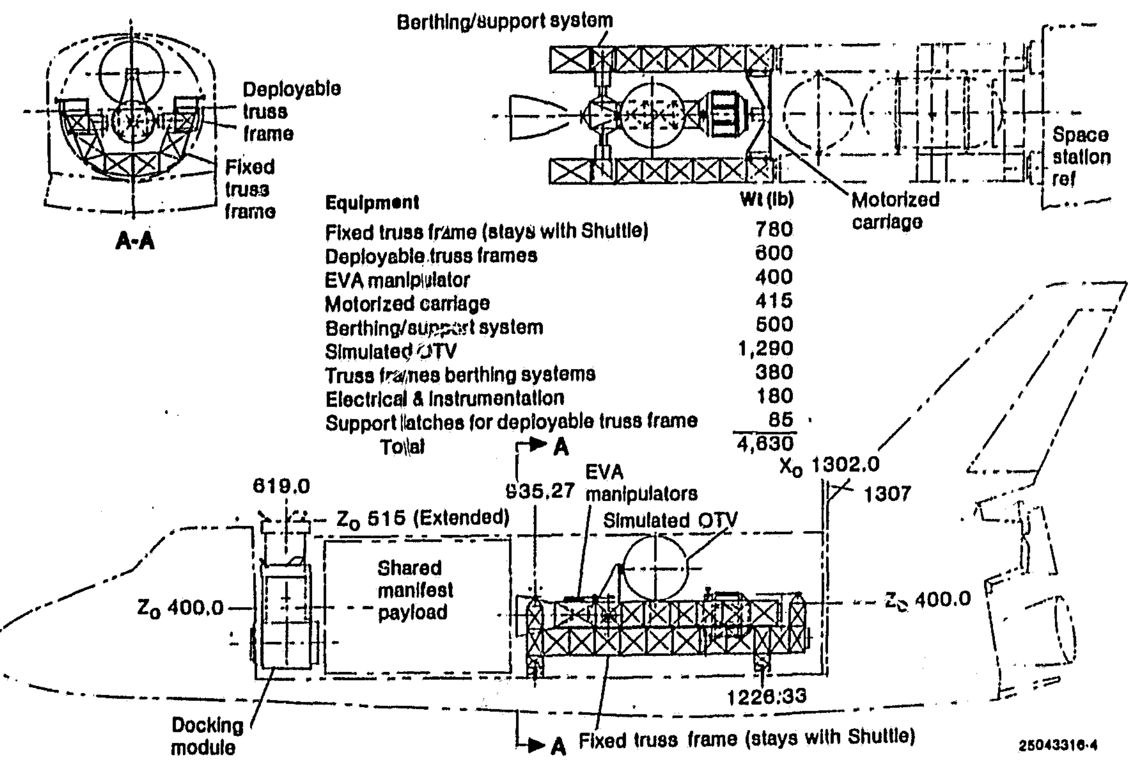
The study groundrules stated that a TMS would be available at the Space Station during the time period for this TDM. Since the TMS is a free flying vehicle, we looked at using a modified TMS as a test bed OTV to do the free flying docking tests. Our investigation indicated that the TMS can be used to meet the OTV docking development tests requirements. We propose that the TMS be used for the free flying OTV docking tests.

3.2 CONCEPTUAL DESIGN

The docking and berthing TDM configuration (see Figure 3-4) consists of two open truss frames, a motorized carriage, a berthing/support system, a simulated OTV and cherry picker type devices for moving/restraining the EVA crewmen. The OTV is attached to the carrige and the berthing system and the entire package (frames, OTV, carriage, berthing system, etc.) is deployed from the Shuttle and attached to the TDM. The TDM is shown in the launch configuration in the Shuttle and attached to the propellant transfer TDM for the orbital configuration. A Space Station RMS is used to transport the TDM from the cargo bay and attach it to the Station.

Figure 3-5 describes the components of the simulated OTV used for the docking and berthing TDM and also for the maintenance TDM. The modules shown can be removed from the simulated OTV for maintenance. The berthing interface is at the aft end of the core module. The module sizes were selected to be representative of actual sizes for an OTV in order to develop the capability to handle this type of equipment in space.



Equipment	Wt (lb)
Fixed truss frame (stays with Shuttle)	780
Deployable truss frames	600
EVA manipulator	400
Motorized carriage	415
Berthing/support system	500
Simulated OTV	1,290
Truss frames berthing systems	380
Electrical & instrumentation	180
Support latches for deployable truss frame	85
Total	4,630

Figure 3-4 Docking & Berthing TDM

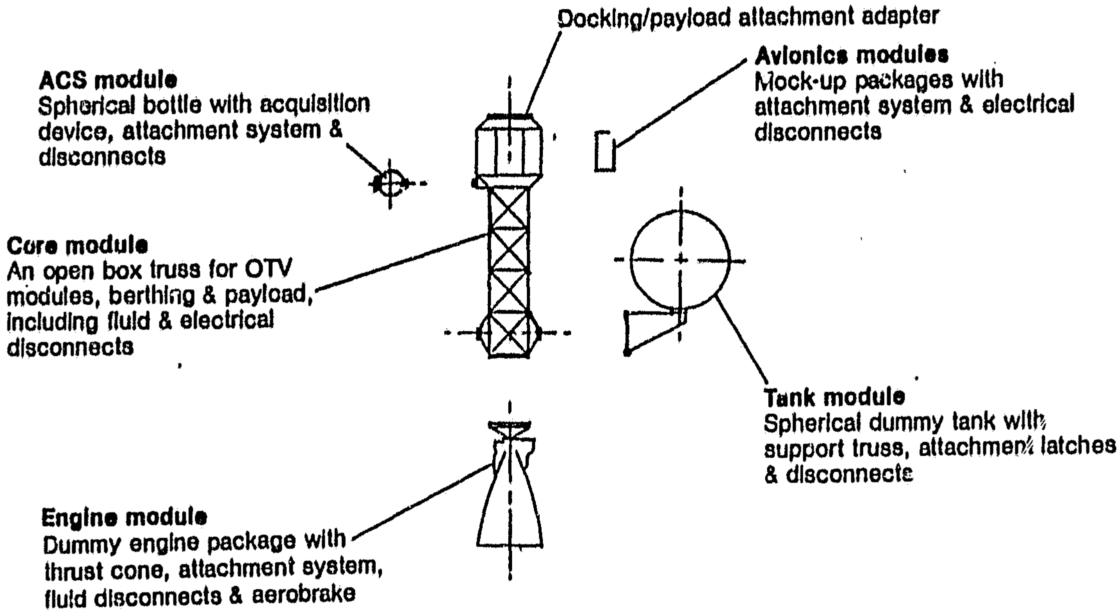


Figure 3-5 Simulated OTV

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3.3 DOCKING AND BERTHING OPERATIONS

An operational OTV with a docking system would dock to the Space Station carriage as shown on the top of Figure 3-6. The left hand picture in the middle of the chart shows the simulated OTV berthed at the Station. To prepare for the docking operations, the forward end of the simulated OTV is disconnected from the carriage and the OTV is rotated 180° using the berthing rotary system. We now use the forward end of the OTV as a docking target removed from adjacent structures. Docking tests are performed using a TMS equipped with an adapter.

For berthing operations the OTV would start in the docking position as shown at the top of Figure 3-7. Berthing operations can be performed by moving the simulated OTV with the carriage into the facility and engaging the berthing system and checking the interfaces.

Depending on the mission docking capabilities required by the operational OTV, an alternative docking method may be the selected approach. If the initial OTV doesn't require the capability to closely approach and attach itself to a satellite for the purpose of replenishing consumables and/or repair, then it may only have rendezvous capability. If this is the case, then a TMS can be used to bring the OTV into the station for docking and berthing. The TMS can be used to position the OTV so that it can be picked up by the TDM RMS. The RMS is then used to dock the OTV to the carriage. Using the carriage, the berthing operation can be performed as described in Figure 3-7.

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The timelines required to perform the docking and berthing tests are included in the summary of TDM activities in Section 7.0. Related functional flows and timelines are provided in Volume 2.

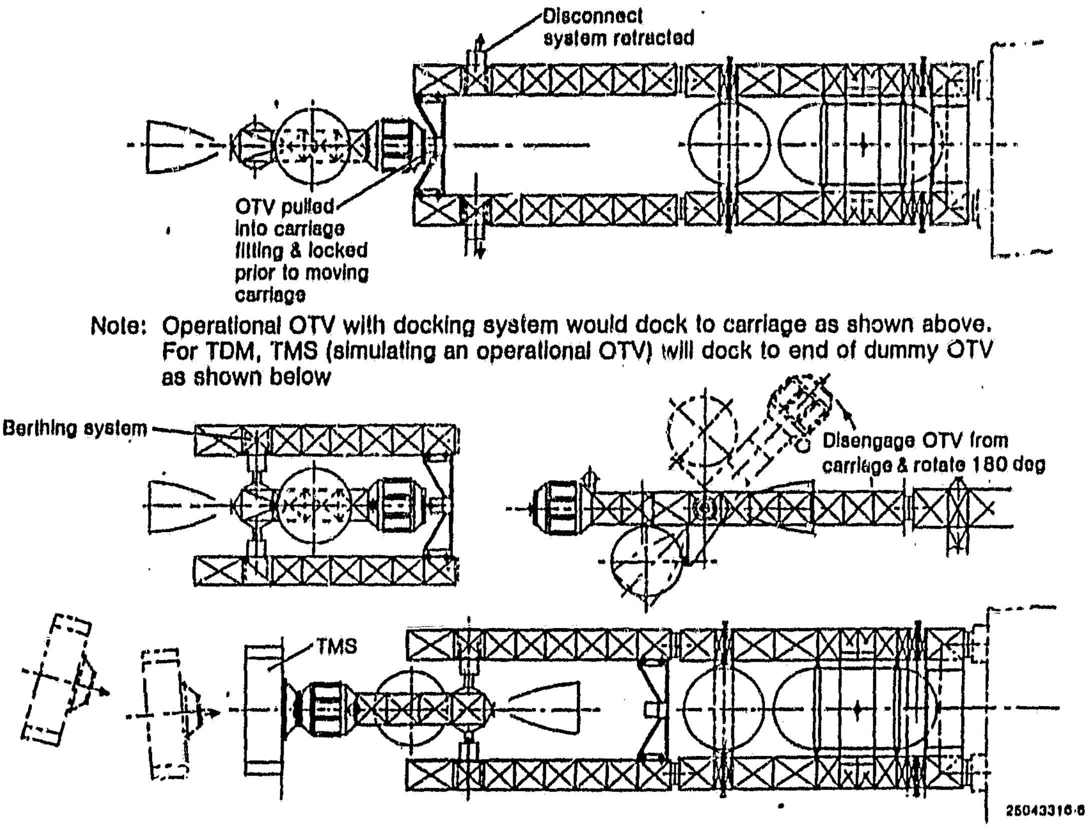

Figure 3-6 Docking Operations

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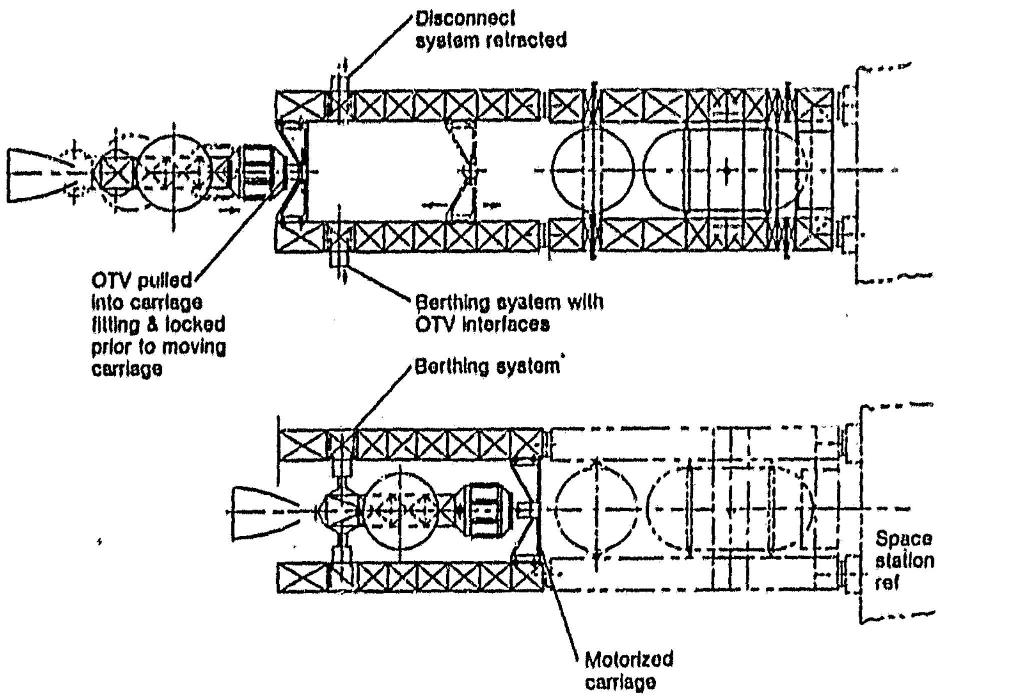

Figure 3-7 Berthing Operations

4.0 MAINTENANCE TDM

Maintenance is considered as the top level activity required to prepare or restore the space-based OTV to achieve or retain a desired operational capability. These maintenance activities or tasks include such operations as handling, assembling, servicing, repair, inspection and checkout.

The requirement to perform these maintenance operations in space to support a truly space-based OTV has driven the conceptual design of our representative vehicle. Consequently, the space-based OTV contains a high degree of desirable maintainability features. The design concept of the vehicle provides for modular construction, with plans for simplified and standardized interfaces, which allow relative ease of vehicle assembly and maintenance at a Space Station facility. The Space Station maintenance facility has also been defined to accommodate these desirable vehicle characteristics.

A prevailing maintenance philosophy has evolved with the integration of the space-based OTV and the Space Station facility. This OTV maintenance philosophy is highlighed in Figure 4-1. The maintenance philosophy relies on three levels of maintenance structure. The actual maintenance operations are further categorized as scheduled and unscheduled activities. Scheduled maintenance encompasses the entire systematic maintenance scenario including servicing and preventive actions required to retain an operational capability. These preventive actions involve inspection, failure detection and some time related remove and replace tasks, such as an engine changeout. Conversely, unscheduled maintenance refers to the unplanned corrective actions required to restore the OTV to an operational level as the result of a vehicle failure.

Three-level maintenance — based on level-of-repair analyses

- I OTV local maintenance
- II Space station maintenance of replaceable units
- III Return-to-earth maintenance

Stock spare parts based on reliability, criticality & cost

- Station storage vs shuttle delivery

Stress modular construction for replacement capability

Provide operational flight instrumentation & built-in test

- Fault isolate to replaceable unit

Optimize EVA vehicle maintenance operations

- Consider safety in hazardous situations
- Tradeoff EVA vs support equipment
  - — TV inspection
  - — Robotic remove & replace

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Figure 4-1 OTV Maintenance Philosophy

Level I maintenance consists of the scheduled and unscheduled activities that occur on the vehicle while it is berthed in the space station maintenance dock. It is preferred that this Level I task involve remove and replace actions, but it could just as well involve some other repair activity occurring on the vehicle. The Level II maintenance category encompasses the repair, or attempted repair, of replaced faulty units at the Space Station. The replaceable units that fit into the Space Station maintenance facility airlock and are determined to be free of contaminants are repaired within the station shirtsleeve environment. Units that cannot be repaired at the station are returned to earth for Level III maintenance. The economic feasibility of repair on earth and return to station on Shuttle concept needs to be determined by an extensive level of repair analysis. Spares provisioning analyses would also identify which units should be stored at the Space Station and which units should be delivered by shuttle on demand. The spares analyses would be based on reliability, criticality and cost criteria.

It is important to keep in mind that these maintenance operational activities and definitions were generated for an operational space-based OTV and Space Station and that maintenance TDM requirements are derived from these operations.

4.1 REQUIREMENTS

The specific maintenance development tasks to be performed on a space-based OTV were identified and are listed in Table 4-1. The three maintenance

Table 4-1 OTV Maintenance Development Tests

Maintenance Task	Development Requirements			Rationale for Space Station Tests
	Ground	Shuttle	Station	
Visual inspection	✓		✓	Preliminary rehearsal & maintenance concept proofing
Fault detection	✓	✓		
Fault isolation	✓			
Remove & replace	✓	✓	✓	Verify EVA accessibility & replacement concept — verify sample procedures & timelines
Unscheduled repair	✓			
System operational verification	✓			
Servicing	✓	✓	✓	Verify & monitor performance of propellant supply system in zero-g environment
Handling	✓	✓	✓	Verify OTV handling concepts & equipment compatibility — verify mating procedures & equipment/EVA integration

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tasks that require concept proofing and equipment evaluation at a space station are visual inspection, remove and replace, and handling techniques. Servicing which is a part of maintenance is covered in Section 2.0. An example of the TDM objectives and requirements for some of these functions is presented in Table 4-2. These requirements were used to drive the TDM conceptual design.

Table 4-2 TDM Objectives & Requirements

Function	Objective	Requirement
1. OTV/maintenance dock handling	Verify handling operations & maintenance dock equipment compatibility Evaluate: • Structural integrity • Mobility & control • Interface integrity • Procedures & timelines	Perform all OTV/maintenance dock handling operations including: • Control equipment utilization • Rotate & lock operations • Interface engagement
2. Service enclosure operations	Demonstrate shelter effectiveness & conduct physical interference evaluation	Extend & retract shelter during OTV maintenance operations. Evaluate interference & limitations imposed by shelter
3. Payload handling & mating operations	Verify payload handling capabilities Evaluate: • Payload handling equipment • IVA capabilities • EVA handling device • EVA capabilities • Special tools • Procedures & timelines	Perform payload handling operations, which include: • Payload transfer from storage to OTV • Payload/OTV mating • EVA operations
4. Visual inspection of OTV components	Verify visual inspection concept & equipment compatibility. Evaluate: • Lighting placement & control • TV monitor effectiveness • EVA/handling device compatibility • EVA accessibility • Special inspection equipment • Procedures & timelines	Conduct OTV inspections involving: • IVA TV monitor activities • EVA operations
5. OTV component remove & replace operations with remote control arm	Verify adequacy of equipment & evaluate crewman/system interface	Exercise remote control arm system to remove & replace designated OTV components, which may include: • Avionics modules • ACS modules • Fuel cells
6. OTV component remove & replace operations utilizing EVA	Verify EVA remove & replace concept & equipment compatibility. Evaluate: • EVA handling device • EVA effectiveness • OTV repairability • Special tools compatibility • Procedures & timelines	Perform EVA remove & replace operations on: • Engine • Tank module

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4.2 CONCEPTUAL DESIGN

The maintenance facility conceptual design is dependent on the docking and berthing TDM assets being in place at the time of maintenance TDM deployment. The maintenance TDM incorporates the berthing/maintenance dock structure and equipment into its facility and performs maintenance operations on the simulated OTV. The RMS attached to the propellant TDM structure will provide the mechanism necessary for semi-automatic or robotic maintenance operations.

The fundamental maintenance facility consists of a non-pressurized mobile structure that is installed on a rail system, which is part of the maintenance dock structure. This maintenance facility configuration was selected for the maintenance TDM, based on the evaluation criteria set forth in the maintenance facility evaluation, Table 4-3. Four options were considered in this trade study; two pressurized hangar/module configurations; the non-pressurized mobile shelter; and an option without a shelter structure. The selected configuration provides the basic needs for OTV maintenance in space and allows for evaluation of a balanced mix of both semi-automatic (or robotic) and EVA maintenance operations. It was strongly felt that the work crew and OTV should be afforded basic environmental protection from meteoroids, debris, and radiation hazards, hence, the selection of having a shelter. The safety evaluation criteria also had a negative impact on the pressurized hangar/module options, because of the possibility of inducing a hazardous situation by placing the engine or other OTV components in a pressurized compartment and allowing residual propellants into a combustive environment. The unwarranted complexity, upkeep and cost of the pressurized configurations, along with proven EVA capabilities were factors which led to the selection of the non-pressurized mobile shelter system as the maintenance TDM facility.

The maintenance shelter/enclosure shuttle installation configuration for transport and subsequent planned assembly at the Space Station is shown in Figure 4-2. It consists of eight rigid panels equipped with accessories such as interconnecting latches, support carriages, and electrical equipment. The panels are arranged so that removal coincides with the assembly sequence. A Space Station RMS is used to remove the panels from the cargo bay and transport them to the TDM. The panels are assembled using the Space Station RMS and during EVA.

The maintenance enclosure has a scissor type crane mounted on an extendable boom equipped with rails for mainpulating large OTV components (see Figure 4-3), such as engines and propellant tank modules, during remove and replace operations. The Space Station must be equipped with a holding fixture for storing these items during maintenance operations.

Smaller equipment items such as avionics packages and ACS modules can be replaced automatically using the RMS located on the propellant transfer module as shown in Figure 4-4. A typical changeout is shown for an ACS module. The same procedures apply to avionics equipment changeouts.

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Space Station Impact	IVA Full Pressurized Hangar	IVA/EVA Pressurized Module/Shelter	EVA Shelter	EVA No Shelter
Facilities	• Complex, stationary hangar • Hangar pressure system	• Partial OTV access module • Module pressure system • Simple mobile shelter	• Simple mobile shelter • No pressure system	• No shelter • No pressure system
Life support system	• Large volume system • 3-5 psi O_2 with complex airlock & replenishment	• 1/10 hangar volume • 14.7 psi O_2 with airlock & replenishment	• Extravehicular mobility unit(s)	• Extravehicular mobility unit(s)
Support equipment	• Standard handling • Standard space tools	• Special & standard handling • Special & standard space tools	• Special handling • Special tools	• Complex handling • Special tools
OTV Maintenance	• Shirtsleeve repair • Propellant servicing outside hangar	• Shirtsleeve & EVA repair • Propellant servicing in place	• Robotic & EVA repair • Propellant servicing in place	• Robotic & EVA repair • Propellant servicing in place
Facilities Maintenance	• EVA repair • O_2 pump & supply system • Temperature regulation system • Airlock seals & vents	• O_2 pump & supply system • Temperature regulator system • Shelter mobility system	• Shelter mobility system	• No maintenance
Spares Storage	• Spares storage space available	• Spares storage space available	• Spares storage space available on inner walls	• Requires spares storage structure
Safety	• Residual propellant hazard • Meteorite & radiation protection	• Residual propellant hazard • Meteorite & radiation protection	• Residual propellant safe • Meteorite & radiation protection	• Residual preoplant safe • No environment protection
Growth potential	• Difficult add-on	• Simple add-on	• Simple add-on	• Easy add-on
Cost	• High cost	• Medium cost	• Lower cost	• Lower cost

Table 4-3 Maintenance Facility Evaluatior

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Equipment	Wt (lb)
Support cradle (stays with Shuttle)	950
Two side panels with support trusses & drive carriages	1,165
Two top & bottom panels	510
Four filler panels	720
Electrical & instrumentation	400
Total	**3,745**

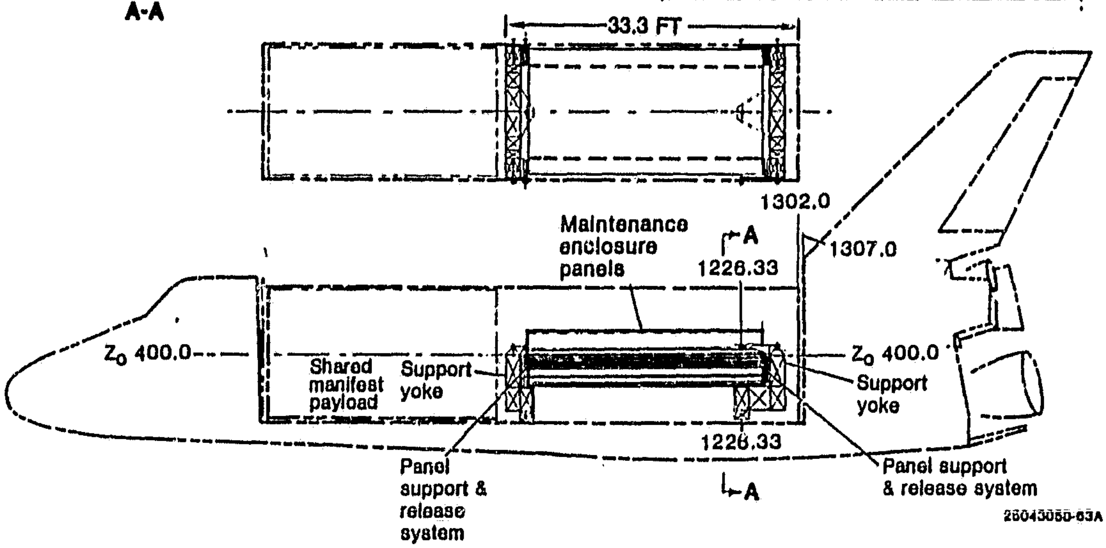

Figure 4-2 Maintenance Enclosure Launch Configuration

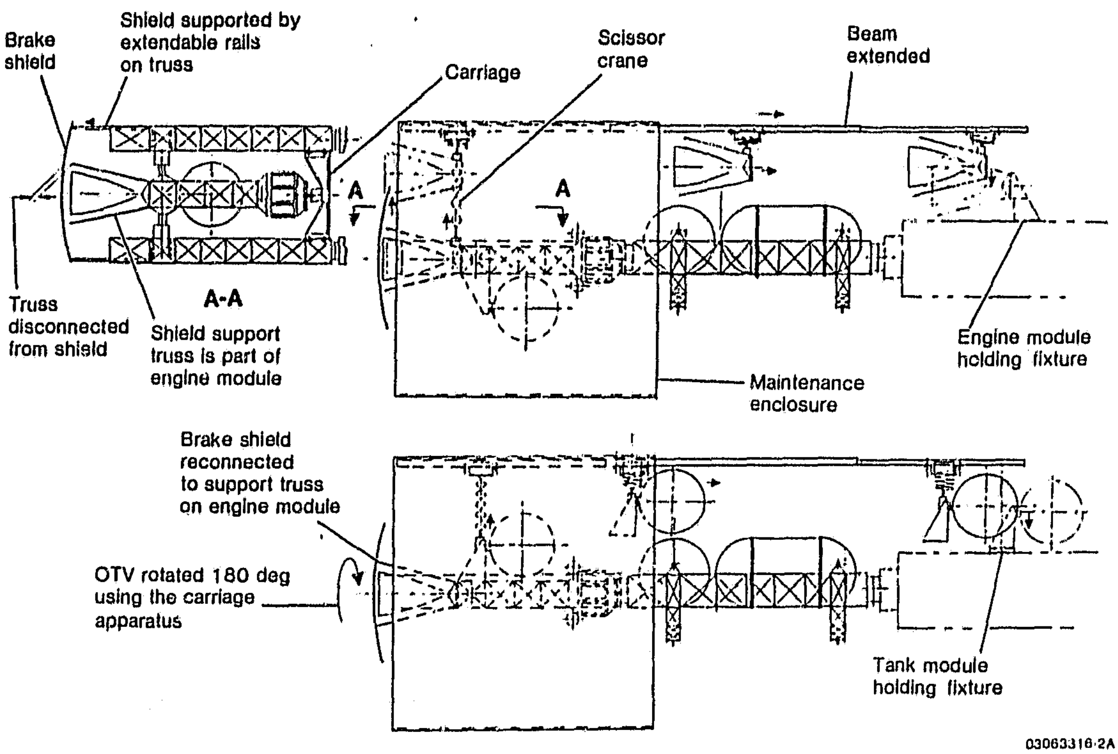

Figure 4-3 Maintenance TDM - Engine & Tank Changeout

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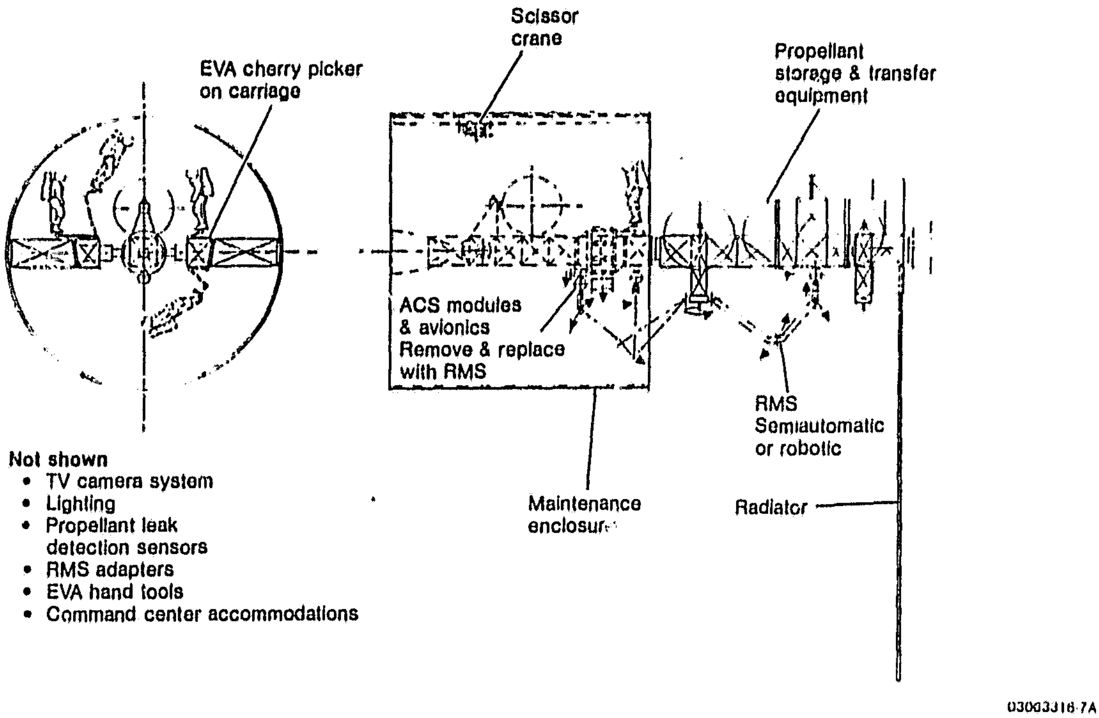

Figure 4-4 Basic Maintenance Facility & Support Equipment

Figure 4-4 also shows the cherry picker equipment necessary for EVA crew member translation to and from the work site. The cherry picker has personnel restraints and is mounted on a rail carriage system that allows the required mobility and OTV access for maintenance EVA operations.

4.3 TDM OPERATIONS

The simulated OTV components that were identified for maintenance concept proofing at the space station are listed in Table 4-4. The generic maintenance tasks that were identified for inclusion in the maintenance TDM were listed in Table 4-2, along with the functional requirements. A more detailed listing, which addresses specifically engine remove and replace activities, is presented in Table 4-5. General Dynamics Convair Atlas and Centaur procedures, along with turnaround operations analyses for a Space Tug, were scrutinized for equivalent ground operational tasks that would satisfy the specific functional requirements. The TDM tasks were then developed using the ground tasks as a reference checklist to assure that all applicable procedures were adequately presented. Of course, the TDM tasks assume their own operational characteristics, because of the differences in design concepts and consideration for the working environment, but it is important to note that the ground tasks formed the foundation for the formulation of these OTV maintenance procedures. The table also reveals the support equipment that are required to accomplish the tasks and whether or not the activity requires IVA or EVA involvement.

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Table 4-4 Subsystems Selected for Maintenance Tests

- Avionic modules — Several representative RF & computer modules for EVA remove & replace & IVA/RMS remove & replace
- Core section — Fuel cell & battery EVA remove & replace
  — ACS IVA/RMS remove & replace
- Engine module — EVA remove & replace
- Tank module — EVA remove & replace
- Aerobrake — EVA repair

Note: Visual inspection to be a distributed function on all tasks

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Table 4-5 TDM Maintenance Summary - Propulsion

Functional Requirements	Equivalent Ground Task	TDM Task	IVA	EVA	Support Equipment Requirements
*Remove engine	• Remove plumbing & electrical wiring • Drain lines & reduce pressure to zero • Disconnect 12 plugs & tie back	• Transfer EVA crew to cherry picker		✓	
		• Check local cherry picker controls & communication		✓	
		• Translate crew to engine work area		✓	
• Detach aerobrake & stow		• Attach aerobrake to rail truss		✓	• Truss extender on truss structure
		• Detach aerobrake from OTV shield support truss		✓	
		• Extend aerobrake away from engine	✓		
• Attach crane to engine	• Install handling tool on engine • Support engine weight with crane	• Attach crane to engine		✓	
• Remove engine	• Remove 2 actuators • Remove 4 engine mounting bolts • Verify engine free for hoisting	• Loosen engine mounting hardware		✓	• EVA tools or latches on OTV
		• Detach engine from OTV		✓	• Special tool or OTV mechanical provisions
• Translate crew to safe area		• Translate EVA crew to safe area		✓	• Cherry picker
• Separate engine from OTV	• Raise engine & place on trailer • Secure engine to trailer	• Withdraw engine with crane	✓		• Scissor crane
• Translate engine & mount to holding fixture	• Install support to LO_2 & fuel lines • Cover gimbal block & tie	• Translate engine to holding fixture			• Engine holding fixture

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The overall maintenance TDM timeline is shown in Table 4-6. Detailed timelines for each maintenance task were prepared and one included in Volume 2.

The overall timelines for the TDM maintenance operations initially encompass an eight day working period. The timelines include two days for maintenance shelter assembly on station. The TDM maintenance activities, when performed sequentially, can be accomplished within a six day working period with a day in between each activity for documentation. The maintenance TDM will be executed on an average fifteen day cycle, conducted six times, during the mission in the same sequence. The fifteen day cycle provides for one day of rest between each EVA operation and three days of rest at the completion of a cycle. The repitition of the TDM allows for variation of conditions and learning curve transition. The total orbital time span for this TDM is approximately three months. (See Section 7.0).

The longest time of operation is 9½ hours, for engine replacement as previously stated and the shortest operating day is 6½ hours for avionics remove and replace. Avionics remove and replace activities will require 4½ hours for EVA operations and 1½ hours for IVA remove and replace actions, using an RMS, on essentially the same task. Both EVA and IVA avionics remove and replace tasks will be accomplished the same day.

The engine module remove and replace task is a two day operation, because we have established that this unit should have a high fidelity interface. The tank module remove and replace task only requires one day for change-out activities, because we envision the interface here to be of lower fidelity than the engine module for this TDM.

Table 4-6 Overall Maintenance Time Line

Day	Task	Time — Hours (0 1 2 3 4 5 6 7 8 9 10)	Man-hours
1	Offload & install shelter structure	(4)	32
2	Final shelter installation & verification	(4)	24
3	Avionics EVA remove & replace — RMS remove & replace	(3) (1)	17
4	Fuel cell & battery EVA remove & replace — ACS RMS remove & replace	(3) (1)	17
5	Remove engine	(3)	26
6	Replace engine	(3)	28
7	Tank module remove & replace	(3)	21
8	Aerobrake repair	(3)	23
		Total man-hours	188

IVA EVA

Note: These maintenance activities should be repeated ≈5 times under varying conditions & parameters to establish the desired data base

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5.0 OTV/PAYLOAD INTEGRATION TDM

OTV payloads assume a wide variety of configurations and perform many different missions. This led us to establish some generalizations and assumptions regarding a probable payload for use on a TDM. The payloads we considered were the payloads that consist of satellites or other spacecraft which are delivered to the Space Station for assembly or maintenance, and where they receive checkout and integration with a carrier vehicle for subsequent transport to their designated orbit or trajectory.

5.1 REQUIREMENTS

The OTV/Payload Development Test Matrix (Figure 5-1) identifies the test objectives and establishes the rationale for determining the test location Note that the majority of the tests will be performed both on the ground and at the space station.

5.2 CONCEPTUAL DESIGN & OPERATIONS

For this TDM it is assumed that a simulated payload would be available at the Space Station and that no additional equipment is needed to be launched. The space station is equipped with an RMS for transporting equipment from the storage area to the OTV (Figure 5-2). Prior to attaching a simulated payload, the service enclosure is moved over the propellant transfer module

OTV Payload Operations	Development Tests		Objective of the Test Program	Rationale for Test Location
	Ground	Space Station		
Handling	X	X	Test the concepts of payload transfer from space station berthing to OTV interface	Ground tests to establish procedures. Space station tests required to confirm procedures in actual working environment
Mating	X	X	Develop the procedures required for mating payloads on an OTV for attachment ease & interface verification	Ground tests to establish procedure & interface design. Space station tests required to verify attachment interface
Checkout	X		Validate the methods of payload checkout after mating & before launch of OTV	Space station tests not required. Checkout from space station is the same as on ground simulator
R&R payload components	X	X	Test concepts of servicing payloads attached to an OTV when berthed at space station	Ground tests to establish RU replacement methods. Space station test required to confirm operations
Demating	X	X	Test the concept of payload removal from OTV due to failure detection	Ground tests to establish procedures. Space station tests required to confirm procedures in actual working environment

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Figure 5-1 OTV Payload Operations Development Test Matrix

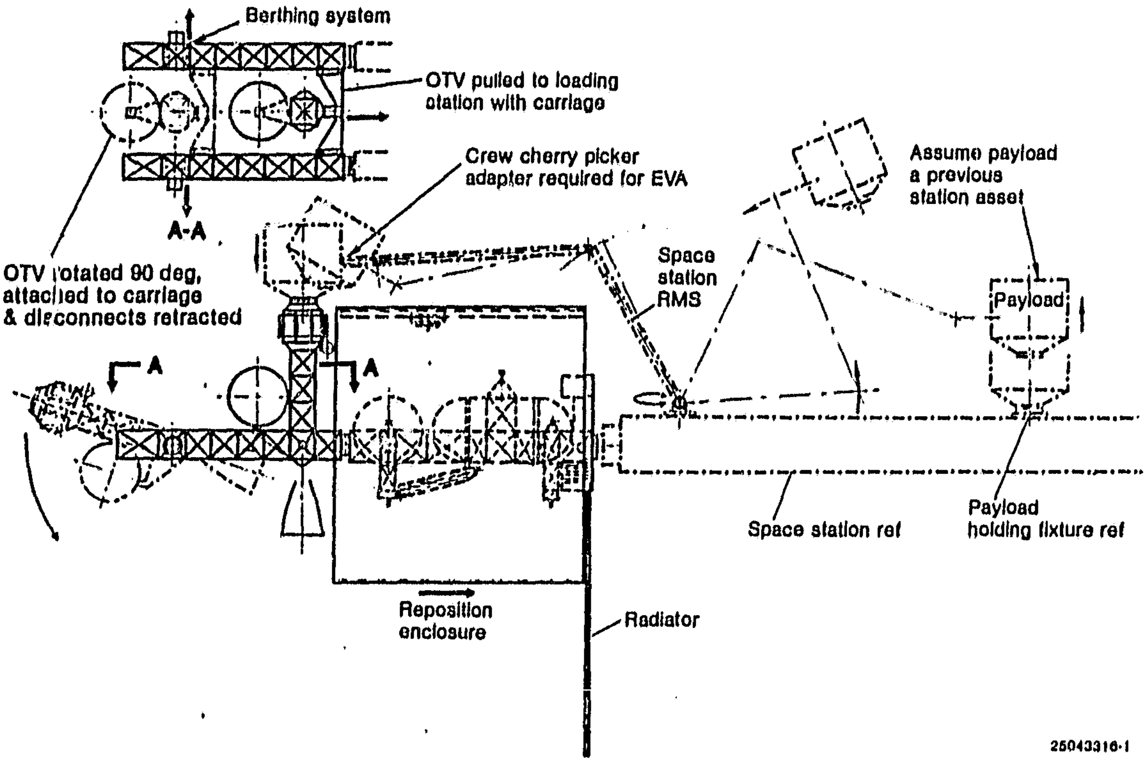

Figure 5-2 OTV/Payload Integration Operations TDM

to allow clearance for the OTV. The OTV is next rotated about the berthing system axis, engaged with the carriage and pulled by the carriage (see A-A) to a position close to the service enclosure. The simulated payload is then transported from a fixture on the space station to the OTV using the space station RMS, mated to the OTV and the integration checked out.

The RMS is detached from the payload and returned to the station where a cherry picker device for EVA crewmen is attached to it. Two EVA crewmen are then carried to the payload and perform a simulated remove and replace operation. After the EVA operations on the payload, the crewmen are returned to the space station.

The top level timeline for the OTV/payload integration TDM is included in Section 7. A detailed timeline is given in Volume 2.

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6.0 COMBINED TDMs DESIGN

The arrangement in Figure 6-1 shows all TDMs packaged for a single dedicated flight. This dedicated flight contains all the equipment previously shown for the multiple flights except for the receiver tank. The receiver tank in this case is the tank module on the simulated OTV. All the same functions that were performed on the individual TDMs can be performed on the combined TDM in the same manner.

This approach has the advantage of reducing the costs of Shuttle launches for the TDMs. However, the disadvantage is that all the equipment must be ready to be launched at the same time. This approach was not pursued in favor of launching TDMs individually with other required space station payloads.

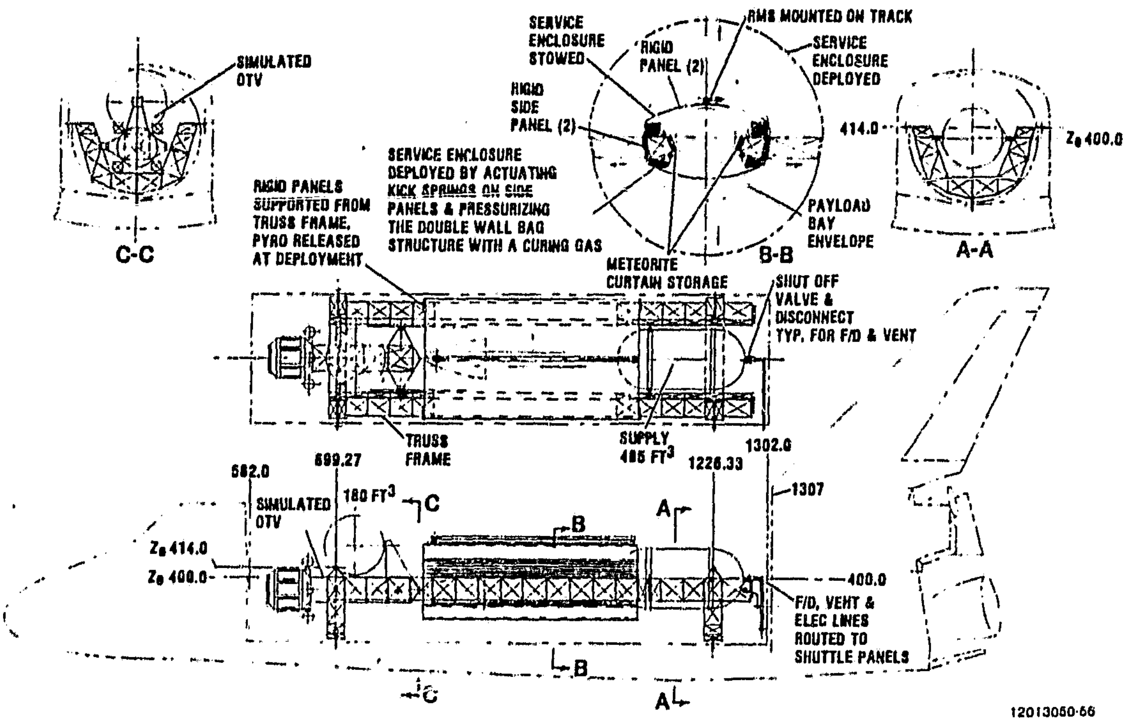

Figure 6-1 Combined TDM

7.0 SUMMARY SPACE STATION ACCOMMODATIONS

For each of the TDMs, the operational requirements have been generated and the Space Station interface and support equipment identified. This section summarizes all the operational activities and the required space station support.

Figure 7-1 reveals all of the planned OTV related TDM activities to be performed on the Space Station and the time allotted for the performance of each of the identified TDMs. The TDM performance time allocations are based on a 90 day Shuttle revisit schedule. The specific mission timelines reflect the proposed recycling scheme for the tests and operations, along with the recommended interval between tests.

Figure 7-2 identifies the total Space Station support requirements for the OTV related TDMs. The expected power required is shown to be approximately 600 watts, plus 500 watts during the running of the propellant test. About 60 ft^3 of volume will be required for the controls and displays in the space station to operate equipment and conduct the tests. Four EVA suits and EMUs are recommended; two for use and two for backup or alternate use. Ground communications will be required for consultation during the tests. The skills and levels for the three crewmen are indicated. These designations are from the instructions generated by NASA for the TDM forms and used in the space station payload data sheets.

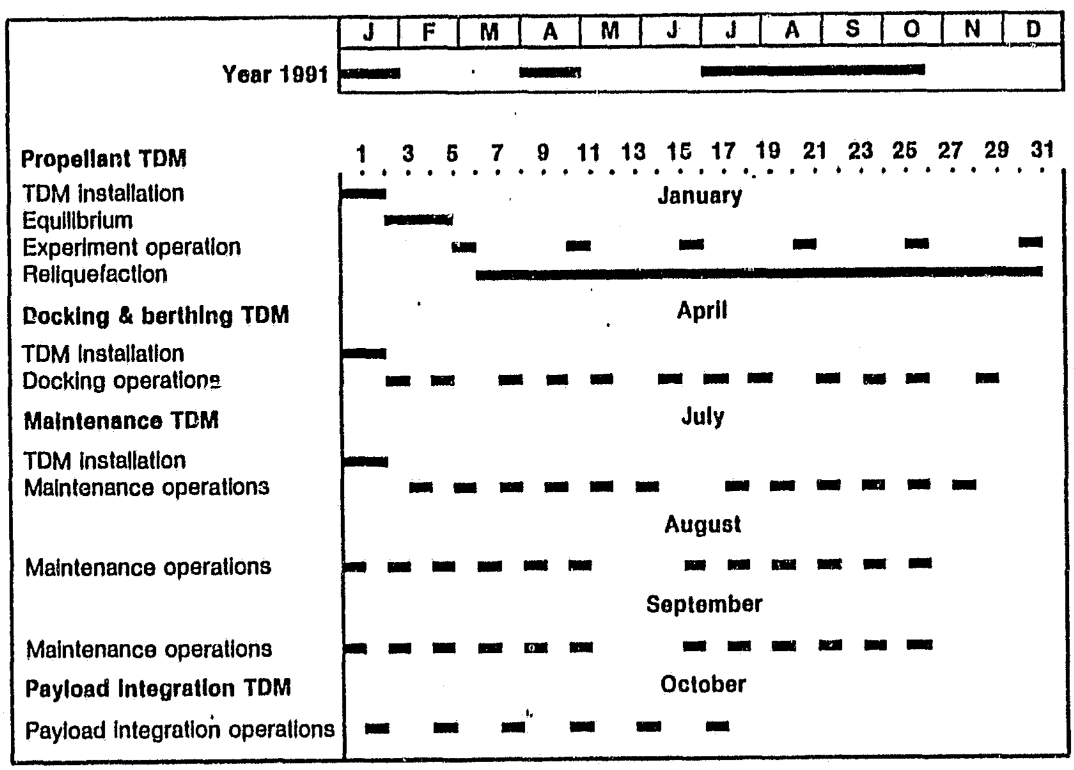

Figure 7-1 Summary of TDM Activities

- Translating RMS & associated controls
  - RMS cherry picker adapter & adapter holding fixture
- TDM to station interfaces
  - Mechanical attachments
  - Electrical interfaces (power, controls, data, communications & TV)
- Electrical power
  - 600W maximum continuous +500W during reliquefaction
- Data acquisition & processing system, remote TV & caution/warning system
- Communication system
  - Ground & TDM (radio frequency & hard line)
- Volume requirements $\approx$60 ft^3 for equipment plus cooling system
- TMS with control station & storage provisions
- Simulated payload with compatible interfaces & representative replaceable units & a payload holding fixture
- (4) EVA suits with EMUs, including helmets with heads-up displays plus cleaning & storage facilities
- Airlock for EVA egress & regress & translation system for EVA crew access to TDM
- Crew Skills:
  - One spacecraft systems professional (skill 7, level 3)
  - Two engineering technicians (skill 5, level 2)

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Figure 7-2 Summary Space Station Requirements to Support the OTV TDMs

8.0 PROGRAMMATIC ANALYSIS

8.1 PLANS AND SCHEDULES

The evolutionary technology development plans have been presented for each of the selected TDMs. They indicate the functions to be tested and where these tests should be conducted, namely on the ground, in a shuttle sortie mission and on the Space Station. The following figures indicate the time frame for those tests in order to efficiently develop the OTV servicing capability.

Figure 8-1 is the development schedule for the Propellant Transfer/Conservational TDM. The launch is proposed for 1 January 1991. Shown also are the recommended ground testing activities and the manifested and proposed Shuttle sortie missions to be performed in support of this TDM. We propose that a propellant transfer sortie mission similar to the one GD defined in Contract 3-321935 for NASA LeRC or the proposed Cryogenic Fluid Management Facility sortie mission, along with the proposed MSFC Large Scale Cryogenic Storage Facility Flight Demonstration mission, be flown in the time period shown to support the development of the TDM.

For reference, a possible development schedule for a space-based OTV (with a 1994 IOC) is shown to indicate how the TDM data can support its development. The TDM will essentially be the flight test verification during C/D of the approach in this area of the space-based OTV.

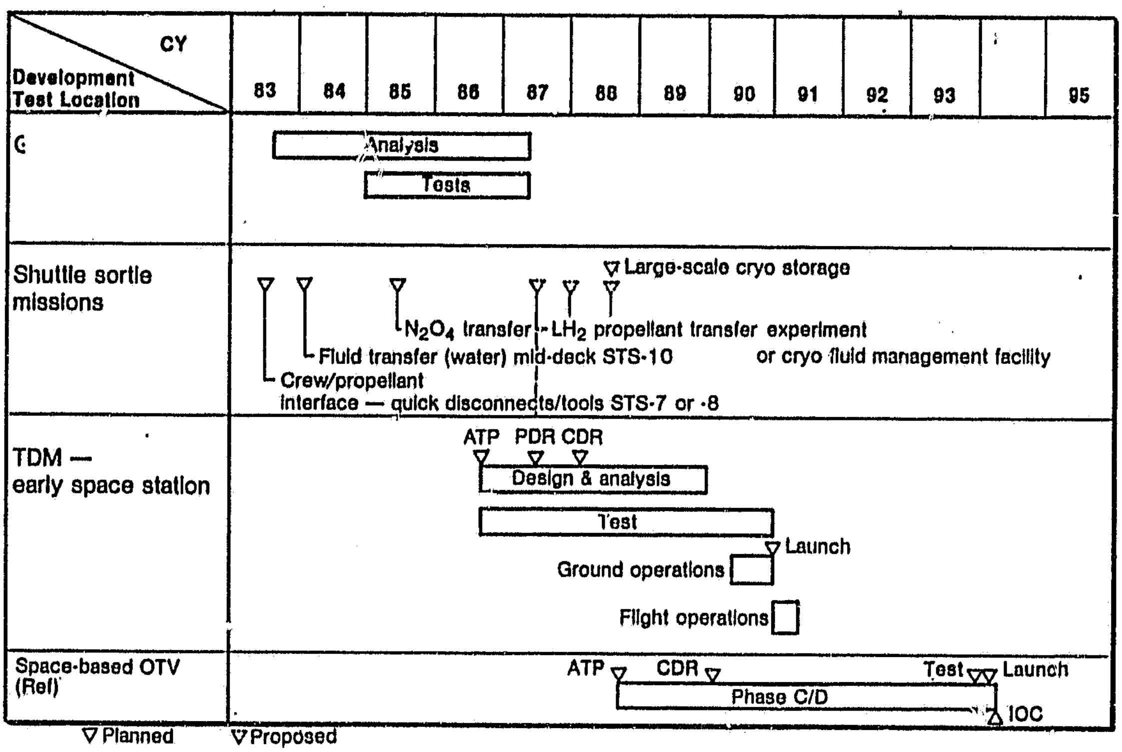

Figure 8-1 Propellant Transfer Storage & Reliquefaction Technology Development Plan

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Shown on Figure 8-2 is the development schedule for the Docking, Berthing and Maintenance TDMs. Since the two TDMs use much of the same equipment, the two are developed together with the launch of the Docking and Berthing TDM occurring on 1 April 1991 and the launch of the Maintenance Enclosure on 1 June 1991. Shown also are the recommended ground testing activities and the manifested and proposed Shuttle sortie missions to be performed in support of the TDMs.

We propose that missions involving EVA and automated remove/replace/handling and zero leak fluid quick disconnect activities be performed to support the PDR of the TDM.

As stated before, the equipment for the OTV/Payload Integration TDM is assumed to be at the Space Station and, since the capability to perform the mission will be developed for the Maintenance TDM, a separate development plan is not required.

8.2 COST ANALYSIS

A cost analysis of the OTV Servicing Technology Development Missions has been conducted and the results are presented herein. These data represent preliminary top level estimates that can only reflect the program definition work performed to date and, therefore, cannot be considered complete or final. They do, however, represent a reasonable estimate based on information available at this time and are useful for planning purposes.

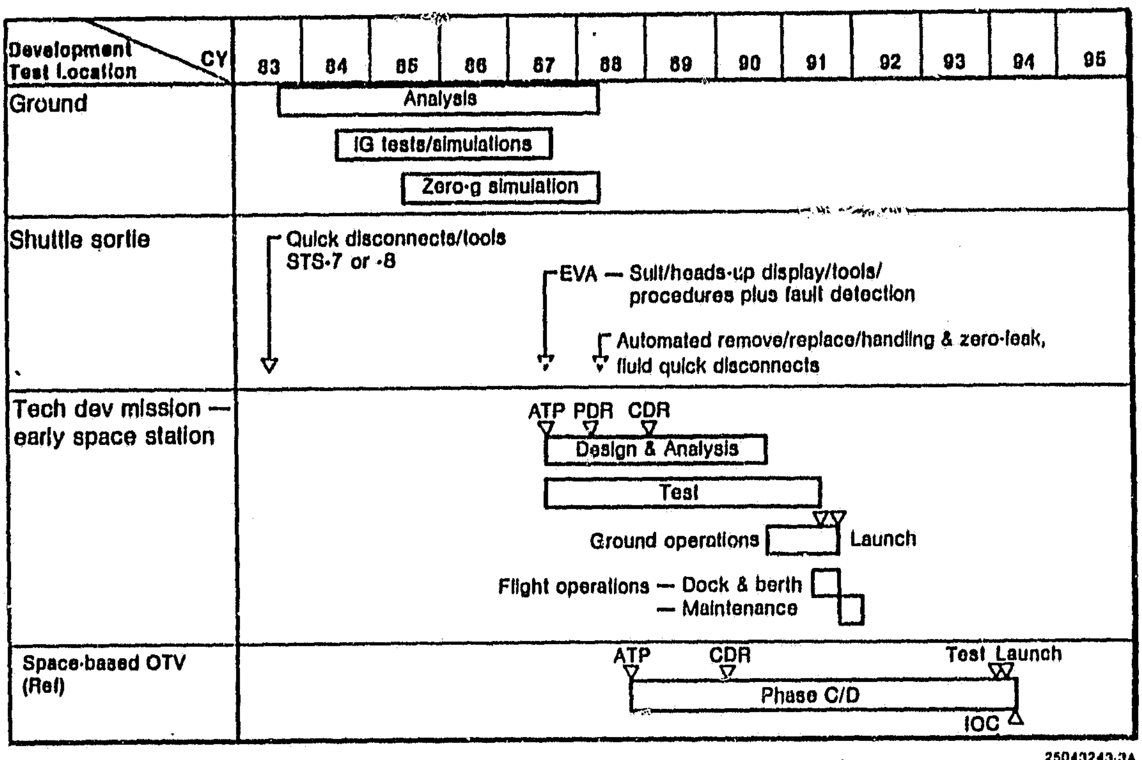

Figure 8-2 Docking, Berthing & Maintenance Technology Development Plan

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A cost work breakdown structure was developed that included all elements, chargeable to the Technology Development Missions project for each of the program phases, i.e., development, production, and operations. This cost WBS set the format for the estimating model, the individual cost estimating relationships (CERs), cost factors or specific point estimate requirements, and, finally, the cost estimate output itself. Cost estimates were made for each element, either at the WBS breakdown level shown or one level below in certain cases. These estimates were accumulated according to the WBS to provide the required development, flight article production, and first flight operations costs.

The resulting ROM cost estimates for the three Technology Development Missions are summarized in Table 8-1. The estimates are given in constant FY 1983 dollars and exclude prime contractor fee. The hardware estimates identify costs for both component development (design, modification, test article procurement) and component test and qualification. Costs shown include software, Ground Support Equipment (GSE), and initial spares. Other wrap-around costs include facility-level design and analysis, system engineering and integration, facility-level testing, and project management. Operations costs and post-flight maintenance and refurbishment costs have been excluded in this estimate, as well as reflight and payload updates or modifications. The OTV/Payload Integration TDM is assumed to have a zero delta development and unit cost at this time.

Table 8-1 Cost Summary

	Cost (FY 83 $M) Nominal	
Propellant transfer/conservation TDM	**60.4**	
• Development		49.2
• Flight article		11.2
Docking & berthing TDM	**29.6**	
• Development		22.2
• Flight article		7.4
Maintenance enclosure TDM	**15.1**	
• Development		11.7
• Flight article		3.4
Total program	**105.1**	

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Annual funding requirements for each TDM are shown individually in Figure 8-3. These funding requirements were calculated using our computerized phased-funding model. Using the costs for each WBS element estimated, the model properly spreads the cost of each element over time in accordance with the program development as previously presented in Table 8-1 and automatically accumulates costs as desired.

There wasn't time during the study to investigate the high cost components in each TDM to see if alternate approaches could be adopted to reduce the costs. For instance, the receiver tank in the Propellant Transfer TDM could also be an Engineering Test Model for the space-based OTV. As such, the total cost of developing and manufacturing it wouldn't have to be borne by the TDM. In the follow-on study phase, the high cost items will be analyzed to find methods to reduce their costs.

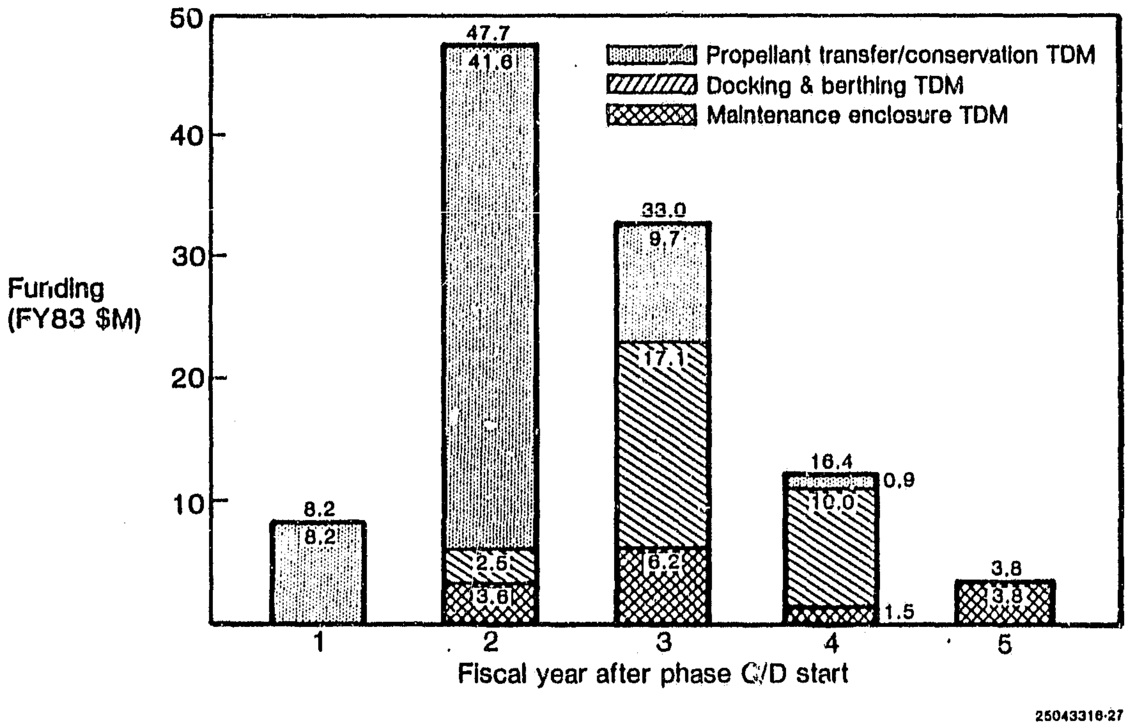

Figure 8-3 Cost Summary - Annual Funding Requirements

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9.0 TDM EQUIPMENT OPERATIONAL USAGE

Figure 9-1 shows a possible approach to making use of the TDM equipment for OTV operational missions. Since the operational OTV is larger in diameter than the simulated OTV, the berthing/maintenance facility must be made larger. The docking/berthing/maintenance TDM trusses can be detached from the propellant TDM trusses and attached to the space station to provide another bay for additional tanks. Two or more TDM tanks can be delivered to the space station to meet the operational OTV capacity. The maintenance enclosure can be enlarged to the required diameter by adding four panels.

The concept has not been studied in any depth in this phase of the study but will be addressed in the follow-on to determine the optimum approach for use of the TDM equipment.

There are a variety of other possible uses for the TDM propellant tanks, other than being used for operational OTV missions. Different size tanks and other arrangements may be more effective for the OTV operational missions. Figure 9-2 lists several viable uses for these tanks. Certainly if one of these applications is the chosen ultimate use for the tanks, then a slightly different capacity may be appropriate.

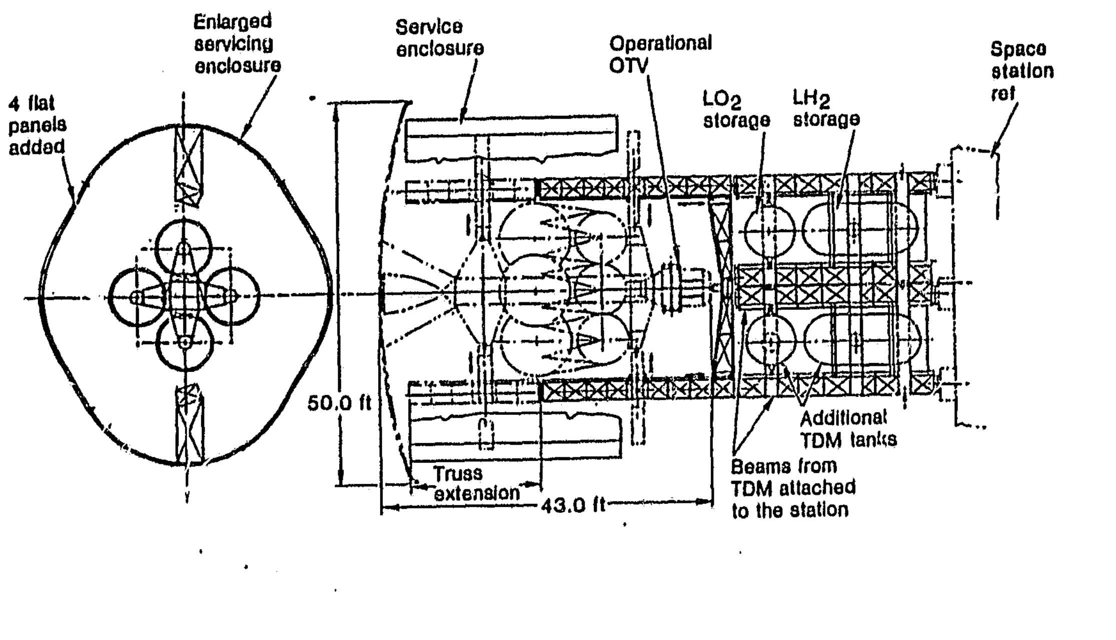

Figure 9-1 Potential TDM Growth to Support Operational Missions

- Source of supply for topping off early ground-based OTVs at the station
- Source of supply for fuel cell subsystems used as backup or augmentation to space station principal power supply
- Possible supply for space-based cryogenic TMS (supercritical propellant), which would eliminate contamination problem
- Propellant supply for space station cryogenic RCS
- Source of supply of cryogenic fluids for superconducting magnets, coolant for sensors, etc

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Figure 9-2 Alternative Usage for TDM Propellant Tanks

10.0 CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

The study conclusions are summarized as follows:

- TDMs that develop/demonstrate the capability to support a space-based OTV are required on the initial space station in the areas of
  - Propellant transfer, storage & reliquefaction
  - Docking & berthing
  - Maintenance
  - OTV/payload integration
- Greater understanding of the space station functions required to support an operational space-based OTV is needed to finalize TDMs
- Integrated technology development plan is needed to focus ground, shuttle sortie & early space station TDMs
- Additional analysis is needed to better understand the TDMs & their impact on the initial space station

Our study has shown, through the operations/functional analysis and evolutionary technology development plan for needed OTV servicing capabilities tasks, that there are requirements to perform TDMs in the four areas shown above. However, there was only time to do a very preliminary analysis of the space station functions required to support an operational space-based OTV. We feel that the basic functions have been identified but that additional work in more depth must be accomplished to finalize the requirements for the TDMs.

In the evolutionary technology development plan task, the study approach called for emphasis on identifying the test requirements for the initial space station and there wasn't time to identify the test requirements for the ground and sortie mission modes to the same depth. As a consequence, an integrated technology development plan has not been generated. This needs to be accomplished to optimize the tests required in each category and refine the TDMs.

With the funding and time available for this study, the definition of the TDMs is very preliminary. Additional analysis is needed to better understand the TDMs and their impact on the station, and make them more cost effective.

10.2 RECOMMENDATIONS

Recommendations for follow-on activity are as follows:

- Perform additional operational analyses to identify space station functions required to totally support an operational space-based OTV

- Determine capability of the initial space station to support/service an OTV (ground-based) for an early operational mission (1990-1992 time period)
- Generate integrated technology development plan
  - Ground
  - Sortie
  - Early space station
- Initiate required technology analytical tasks
- Initiate and/or update recommended sortie mission experiment definitions
- Continue definition studies for technology development mission for early space station

Most of these recommendations have been incorporated into the work statement for the follow-on phase to this contract. However, timely initiation of required technology analytical tasks to develop the OTV servicing capability and initiation and/or update of recommended Shuttle sortie missions to support this development needs to be accomplished outside of the follow-on contract by the appropriate NASA technology managers.